glass vessel filled with kerosene, through which no ultra-violet light could have been transmitted. To put the matter to final test, I lighted a magnesium wire in close proximity to the receiver without producing any effect. Thick blocks of wood of ebonite and of pitch were interposed without checking the action. I then used polarised electric radiation, and interposed a book analyzer, 6 cm. in thickness; when the analyzer was held parallel, there was a vigorous action, but when it was held in a crossed position all action was stopped. No visible or heat radiation could have been transmitted through such a structure, and there can be no doubt that the action was entirely due to electric radiation.

It would be interesting to investigate whether the observed action of electric radiation on a potassium receiver is in any way analogous to the photo-electric action of visible light. I have commenced an investigation on this subject, the results of which I hope to communicate on another occasion.

BAKERIAN LECTURE.—"The Crystalline Structure of Metals." By J. A. EWING, F.R.S., Professor of Mechanism and Applied Mechanics in the University of Cambridge, and W. ROSENHAIN, 1851 Exhibition Research Scholar, Melbourne University. Delivered May 18, 1899.

(Abstract.)

In a previous communication, read to the Society on March 16, a preliminary account was given of some of the results the authors had arrived at in studying metals by the microscopic methods initiated by Sorby, and pursued by Andrews, Arnold, Behrens, Charpy, Osmond, Roberts-Austen, Stead, and others. The present paper deals with a development and extension of the same work. It relates chiefly, though not exclusively, to the effects of strain, and the relation of plasticity to crystalline structure.

It is well known that the etching of a polished surface of metal reveals, in general, a structure consisting of irregularly shaped grains, with clearly marked boundaries. Each grain is a crystal, the growth of which has been arrested by its meeting with neighbouring grains. This view, as Mr. Stead has pointed out, is strongly supported by the appearance of the etched surface under oblique illumination, when the several grains are seen to reflect light in a way which is consistent only with the idea that on each there is a multitude of facets with a definite orientation, constant over any one grain, but different from grain to grain. The formation of such a structure is well exhibited, on a relatively enormous scale on the inner surface of a cake of solidifying

bismuth, from which the still molten metal has been poured away. Another striking example of this structure is seen in steel containing about $4\frac{1}{2}$ per cent. of silicon. The fractured ingot of this material exhibits large crystals, and by deeply etching a polished surface Mr. Stead has obtained a beautiful development of the regularly oriented elements of which the crystalline grains are built up* on a scale so large as to require but little magnification.

The authors have obtained much evidence that this structure is typical of metals generally. Probably under no condition does any metal cease to be crystalline.

The crystalline character of wrought-iron bars or plates is seen when the polished surface is etched, not merely by the general appearance of the grains under oblique light, but by the development of geometrical pits on the surface. These pits have a definite orientation over each grain, and the orientation changes from one grain to another. Usually in the purest commercial iron their outline is that of plane sections of a cube, but occasionally they are apparently plane sections of an octahedron. In some instances isolated and comparatively large pits only are seen; in others nearly the whole surface of a grain, when viewed under a magnification of 1000 or 2000 diameters, is found to be covered with small as well as large pits, geometrically similar and similarly oriented. Photographs of these are given in the paper.

For the purpose of producing smooth surfaces in the more fusible metals, without polishing, the metal was poured in a molten state on a plate of smooth glass. The surface produced in this way shows well the boundaries between the grains, and in some cases it also exhibits the crystalline character of the grains in a remarkable way by means of geometrical pits, which are apparently formed on the surface in consequence of the presence of small bubbles of air or, more probably, of gas given out from the metal itself during solidification. Cadmium shows these particularly well, and they are to be observed also in tin and zinc. These air-pits are seen, under 1000 diameters, to be negative crystals, similar and similarly oriented on each grain, and, in cadmium, to have outlines which suggest that they are sections of hexagonal prisms. Their characteristics are exhibited in the photographs, which also show how the boundaries between the grains are emphasised by the collection there of air or of gas given off by the metal during solidification. The true boundary is merely the trace of a surface on a plane, but it may be broadened out in this way into a wide shallow channel.

The effects of strain have been examined in many metals, using surfaces prepared either by polishing or by casting against a smooth plate. When any metal is strained beyond its elastic limit in any way, the surface of each crystalline grain becomes marked by one or more

* 'Journal of the Iron and Steel Institute,' 1898.

systems of lines running in a generally straight and parallel fashion over it. The direction of the parallel lines changes from grain to grain. Thus these lines serve to mark out one grain from another in a metal which, although polished before straining, has not been etched to develop the boundaries. As straining proceeds, the lines become more and more numerous and emphatic, and two, three, or four systems appear on each grain.

The nature of these lines has been described in the authors' paper of March 16. They are slips along cleavage or gliding planes in the crystals. The effect of each slip is to develop a step on the polished face. The short inclined surface forming this step looks black under vertical illumination, but shines out brightly when oblique light of a suitable incidence is used. These slip bands, as they were named in the previous paper, are thus seen as narrow dark or bright bands, accordingly to the nature of the lighting.

The authors have developed slip-bands in iron, copper, gold, silver, platinum, lead, tin, bismuth, cadmium, aluminium, nickel, as well as steel, brass, gun-metal, and various other alloys. So far as the observations go, they occur in all metals.

The slip-bands are in themselves an evidence of crystalline structure, and, further, they show how such a structure is consistent with plasticity, and how it persists after plastic strain has occurred. The "flow" or non-elastic strain of a metal occurs through numerous finite slips taking place on the cleavage or gliding surfaces in each of the crystalline grains of which the metal is an aggregate. The elementary pieces which slip on one another retain their primitive crystalline character.

Further, if the movement of the pieces with respect to each other in any one grain is a movement of translation only, their orientation should remain uniform in each grain.

That this is actually the case is demonstrated by examining specimens of metal which had been violently deformed without any subsequent annealing or heating. In metal that has been rolled or hammered in the cold state, or deformed by tension or compression or strain of any kind, however severely, the grains are still seen where a surface is polished and etched. Their form is much changed by the strain which the piece has undergone. But the fact that they have retained their crystalline structure is demonstrated when, after polishing, the piece is subjected to a slight additional strain of any kind, for the effect of this additional strain is to develop slips of the same general character as before. Further evidence to the same effect is given by the fact that etching the polished surface of a very severely strained piece develops geometrical pits, which are similar and similarly oriented over the face of each grain, notwithstanding the great distortion which the grain has suffered as a whole. The effects of oblique lighting in

metal which is polished and etched after severe straining are referred to as illustrating the same point. The persistence of crystalline structure is demonstrated by micro-photographs of the section of a bar of Swedish iron which had been rolled cold from a diameter of $\frac{3}{4}$ inch to a diameter of $\frac{1}{2}$ inch without subsequent heating. The outline of the grains is much distorted, but the orientation of the crystalline elements remains constant within each individual grain.

The slips in metals which exhibit a cubical crystalline structure on etching are in some instances parallel to the faces of the cubes, and are very frequently inclined to the faces, apparently along the octahedral planes. Stepped lines are frequently seen, and also lines which appear curved probably in consequence of numerous steps which are unresolved even under the highest powers. In exceedingly plastic metals such as lead, copper, and gold, the lines are particularly straight. A piece of lead cast against glass to produce a smooth surface gives, when slightly strained, a splendid display of slip-bands, and the boundaries of the grains are sharply defined by the meeting of the lines on one grain with those on its neighbours. Another way to get a clear lead surface for the purpose of showing slip-bands is to press a freshly cut piece of the metal with considerable force against a smooth object. Photographs of slip-bands in iron, gold, silver, lead, copper, and other metals are given in the paper.

When a metal is fractured the grains do not as a rule part company at their boundaries, but split along cleavage surfaces. It is to this that the crystalline appearance, obvious in many fractures, is due.

In several metals the authors find that "twinning" takes place in the crystalline structure as an effect of strain. Samples of copper, which in the original cast state gave no evidence of the existence of twin crystals, were hammered or otherwise wrought, and were then found to be full of twins. The twinning produced in this way survived after the wrought copper had been raised to a red heat and allowed to cool. Similar results were obtained in gold and in silver; the metal in the cast state did not show twins, but they were found after the metal had been wrought and subsequently softened by annealing. An example of twinning was observed in nickel after the application of a somewhat severe strain. Twins were readily developed in cadmium by strain, apparently as a result of the slight strain which was applied for the purpose of developing slip bands. They were also found in lead, zinc, and tin, either as a primitive feature in the crystallisation or produced by straining. The twinning frequently takes the form of a large number of parallel bands within a single grain, and a twin band due to strain in one grain is sometimes associated with a twin band in neighbouring grains, the bands being continuous except for a change in orientation in passing from grain to grain.

Photographs of twin bands in copper, gold, lead, and other metals are

given, showing the twin bands as revealed by a cross-hatching of parallel slip lines, the sets of lines being parallel to one another in alternate bands of the twin. The twinning under strain which we have observed in various metals is similar to that which is known to occur in calcite. It may be regarded as a result of slip accompanied by a definite and constant amount of rotation on the part of the molecules.

From this point of view there are two modes in which plastic yielding occurs in a crystalline aggregate. One is by simple slips, where the movements of the crystalline elements are purely translatory and their orientation is consequently preserved unchanged. The other is by twinning, where rotation occurs through an angle which is the same for each molecule in the twinned group. Both modes are often found not only in a single specimen of metal but in the same crystalline grain.

At the suggestion of Messrs. Heycock and Neville, the authors' examination of the effects of strain has been extended to certain eutectic alloys. The structure of such alloys has already been described by Osmond, with whose observations these are in agreement. The alloy generally exhibits rather large grains, the structure of which is very different from that of pure metals, for it consists of an intimate intermixture of two constituents, one of which appears as separate or dendritic crystals on a field formed of the other constituent. The two are seen forming an exceedingly minute and complex structure within each of the large grains of which the alloy is made up. Straining has the effect of making this intimate structure more apparent, by causing slips which set up differences of level between pieces of one and the other constituent.

A study of the micro-structure of alloys suggests a possible explanation of the peculiarities they present in regard to variation of electrical conductivity with temperature. The two constituents may behave individually as pure metals in this respect, but if their coefficients of expansion are different the closeness of the joints between them will depend on the temperature. Thus if the more expansible metal exists as plates, or separate pieces of any form within the other, the effect of heating will be to make the joints between the two conduct more readily, with the result of reducing the increase of resistance to which heating would otherwise give rise, and in extreme cases with the effect even of producing a negative temperature coefficient. The high resistance of alloys generally may be ascribed to the large number of joints across which the current has to pass.

In casting metals against glass and other smooth bodies for the purpose of getting a surface fit for microscopical examination, a surface is occasionally produced which not only shows the true boundaries between the crystalline grains, but also additional markings which simulate

boundaries in a very curious manner. These pseudo-boundaries are often polygonal in form, like the real boundaries, and have an intimate geometrical association with them. Under low powers they are in some instances difficult to distinguish from true boundaries; but the distinction is apparent under high powers, and it becomes obvious as soon as slip-bands are developed by the straining of the metal. The pseudo-boundaries are found to consist in small variations of level in the surface of the grains in which they occur. Their form suggests that they are projections upon the surface of real edges below. They occur very conspicuously in cadmium, especially when it is cast on a cold surface, and less conspicuously in zinc. It is probable that in the strain set up by unequal cooling after the metal has solidified, the lower edges of the crystalline grains project a sort of image of themselves on the surface by slips, or possibly by narrow bands of twinning. The effect resembles that of a Japanese "magic" mirror, in which slight inequalities of the surface, corresponding to a pattern behind, cause light reflected from the mirror to produce an image in which a ghost of the pattern may be traced.

The authors regard their experiments as establishing the conclusion briefly stated in their previous paper, to the effect that the plasticity of metals is due to the sliding over one another of the crystalline elements composing each grain, without change in their orientation within each grain, except in so far as such change may occur through twinning.

"The Yellow Colouring Matters accompanying Chlorophyll, and their Spectroscopic Relations." By C. A. SCHUNCK. Communicated by EDWARD SCHUNCK, F.R.S. Received April 20,—Read May 18, 1899.

[PLATE 6.]

The yellow colouring matters dealt with are those accompanying chlorophyll in healthy green leaves and which are extracted along with it by means of boiling alcohol.

This group of yellow colouring matters is generally known by the name xanthophyll, a term first used by Berzelius, who was the first observer to express the belief that a yellow colouring matter pre-exists along with the green colouring matter in alcoholic extracts of green leaves. The subject has subsequently received the attention of many investigators—Fremy, Michels, Millardet, Müller, Tinisnaseff, Gerland, Raunenhoff, Askenasy, Stokes, Sorby, Tschirch, Kraus, Filhol, Hansen, and Schunck. The principal results arrived at by these investigators are as follows:—Filhol noticed that by treating crude alcoholic chlorophyll solutions with animal charcoal it is possible to